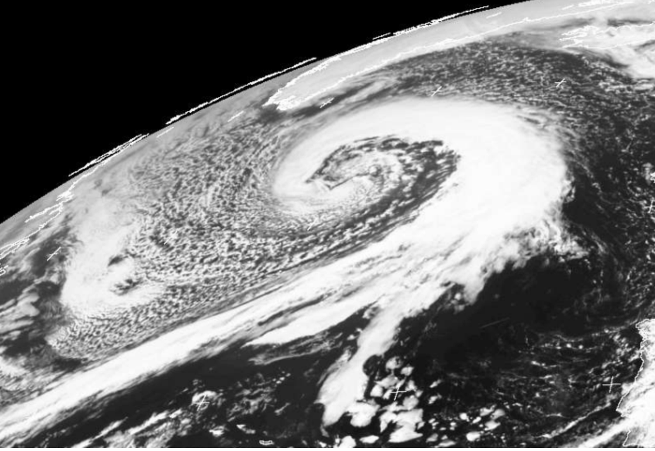
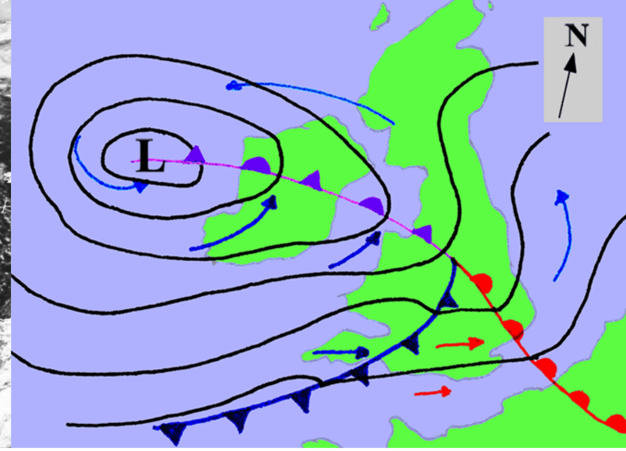




Predictability of Extratropical Cyclones

(in the North Atlantic/European Regions)

Lizzie Froude

Environmental Systems Science Centre

University of Reading

With thanks to Kevin Hodges, Robert Gurney and Lennart Bengtsson

email: lsrf@mail.nerc-essc.ac.uk homepage: www.nerc-essc.ac.uk/~lsrf

Outline

- Motivation: Importance of predicting extratropical cyclones
- Review of previous cyclone predictability studies
- Storm tracking methodology for assessing cyclone prediction/predictability
- Comparison of ensemble prediction systems (EPS) from TIGGE
- Regional analysis of ECMWF EPS
- Future Work
- Conclusions

Importance of Predicting Extratropical Cyclones

- Important for day-to-day weather in the midlatitudes
- Stormy, wet and windy weather
- **Beneficial:** Provide essential rainfall
- **Damaging:** Floods and strong winds
- Examples:
  - **Great October Storm (1987)** hit southern England and north-west France. Caused severe damage and 18 people died. Badly predicted.
  - **Storms Lothar and Martin (December 1999)** hit Europe (1 day apart). Large economic loss in France, Germany and Switzerland and more than 80 deaths. High speed of storms associated with unusually strong westerly winds.

Individual Cyclone Predictability Studies

- Numerous studies of **individual** extratropical cyclones
  - Motivated by severity or deficiencies in the forecasts
  - Great October Storm of 1987 (**Morris and Gadd 1988**)
  - Storms Lothar and Martin of 1999 (**Pearce et al. 2001**)
- Not limited to operational forecasts of the time, current models used to study prediction of past severe cyclones
  - **Jung et al. (2004):** ECMWF model, reforecast 3 major European storms of 20th century including Oct 1987 storm
  - Track and intensity well predicted, but timing difficult
  - **Jung et al. (2005):** continued by exploring prediction of the storms by ECMWF ensemble prediction system (EPS)
  - EPS able to predict large forecast uncertainty in the timing of Oct 1987 storm 4 days in advance

Impact Studies of Individual Cyclone Prediction

- Studies of the impact some "*controllable factor*" has on cyclone prediction
- **Types of Observations:**
  - **Kuo et al. (1997):** GPS refractivity data, extreme cyclone in North West Atlantic in 1989
  - **Xiao et al. (2002):** satellite derived winds, mid-Pacific cyclone from 1998
  - Penn State/NCAR mesoscale model (MM5)
  - Improvements in cyclone position and intensity
  - **Pouponneau et al. (1999):** upper level wind aircraft data, Atlantic cyclone in 1994 using Meteo-France forecast system.
  - Automated cyclone tracking system (Baehr et al. 1999) to track relative vorticity maxima
  - **Suggest use of automated tracking algorithm to measure forecast skill**

Impact Studies of Individual Cyclone Prediction

- **Targeted Observations:**
  - **Leutbecher et al. (2002):** French storms of 1999 and storm that hit Denmark also 1999
  - ECMWF forecast system
  - Overall observations improved cyclone prediction
- **Initial State:**
  - **Zou et al. (1998):** Cyclogenesis of Atlantic storm 1989, MM5 model
  - Apply optimal perturbations to initial conditions
  - Indication of severe cyclone earlier in forecast cycle
  - **Langland et al. (2002):** U.S. east coast cyclone 2000, U.S. Navy global forecast model
  - Optimal perturbations improved prediction of cyclone position
  - Often ensembles used to study initial state: e.g. **Sanders et al. (2000), Hacker et al. (2003)**
  - Cyclone simulations: **Zhu and Thorpe (2006)**

Need Statistical Analysis!

- Lots of studies of individual cyclones, but need statistical analysis
- Statistical studies less numerous – large computational requirements
- First statistical study **Leary (1971):**
  - Sample of 417 storms from Nov 1969 - Feb 1970
  - NMC (now NCEP) model
  - Manually identified and tracked cyclones from analysis and forecast pressure maps
  - Systems with at least one closed isobar
  - Cyclones over ocean underpredicted intensity
  - Cyclones in lee of the Rockies were too deep
  - Forecast tracks generally lie to the right of analysis tracks
  - Silberberg and Bosart (1982) got similar results

Statistical Studies of Cyclone Predictability

- **Semiautomated studies**
  - Don’t have to manually enter data from surface pressure maps into computer
  - Grum and Siebers (1989) and Grum et al. (1992)
  - NMC nested grid model (NGM)
  - Cyclone intensity overpredicted over land and underpredicted over ocean
  - Move too slowly and cold bias
- **Model comparison**
  - Sanders (1992) compared NMC, ECMWF and UK Met Office models over central and western North Atlantic
  - NMC had highest performance
  - Verified against NMC analyses – bias?
  - Different observations available to different weather centres

Statistical Studies of Cyclone Predictability

- European studies:
  - Girard and Jarraud (1982) and Akyildiz (1985)
  - Compared ECMWF grid point model (then operational) and a spectral model
  - Propagation speed too slow in grid point model
  - Also too slow for fast moving cyclones in spectral model
  - Growth and decay rates too small in grid point model
  - More realistic in spectral model

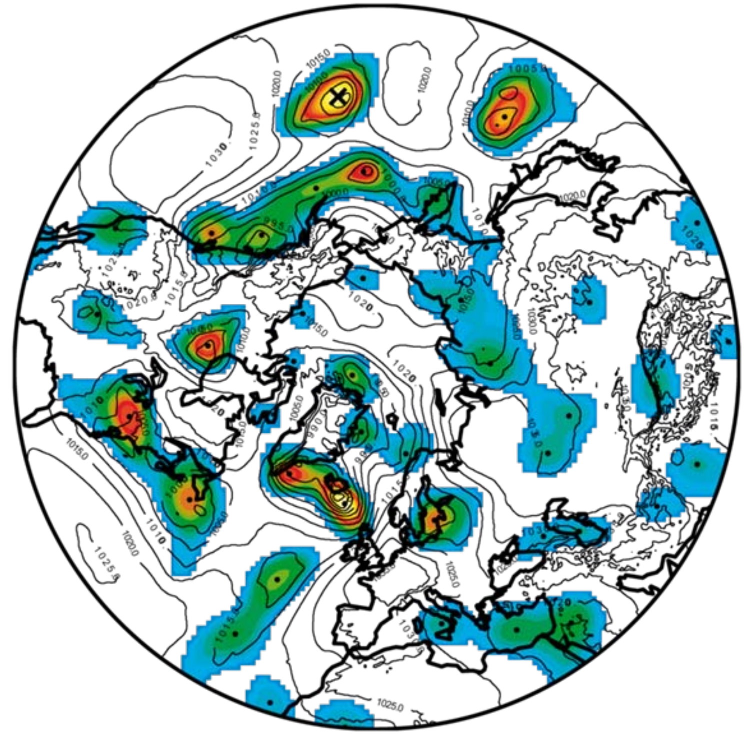
Limitations and Requirements

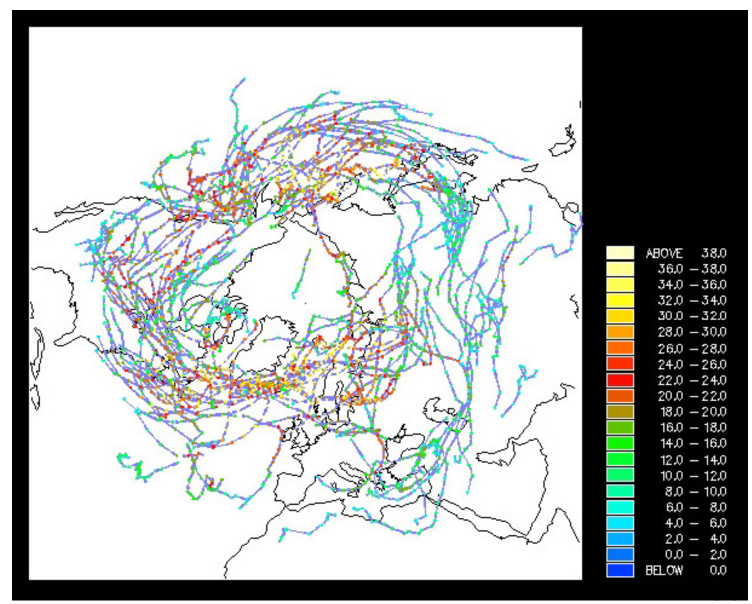
- Past studies limited by time consuming task of manually identifying and tracking features
- Statistical studies are15 years or more old

- Need statistical analysis of prediction of extratropical cyclones by current NWP
- Need to use fully automated method of cyclone identification and tracking

TRACK

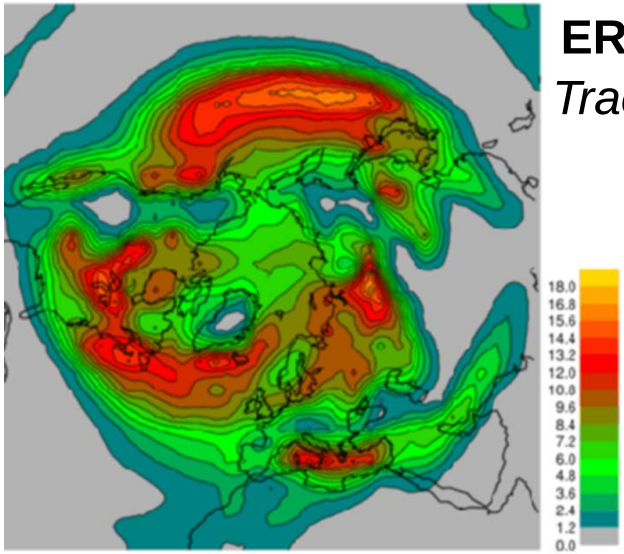
- Storm Identification and tracking software (Hodges 1995)
- Identifies feature points (low pressure centres or vorticity max and min) through a time series of data.
- Filter – remove background (n≤5), T42 resolution
- Normally use 850-hPa relative vorticity (ξ_{850})
- Links points together to form trajectories of storms path (storm tracks)
- Minimise cost function to form smooth tracks
- Tracks filtered:
  - Last at least 2 days
  - Travel further than 1000 km



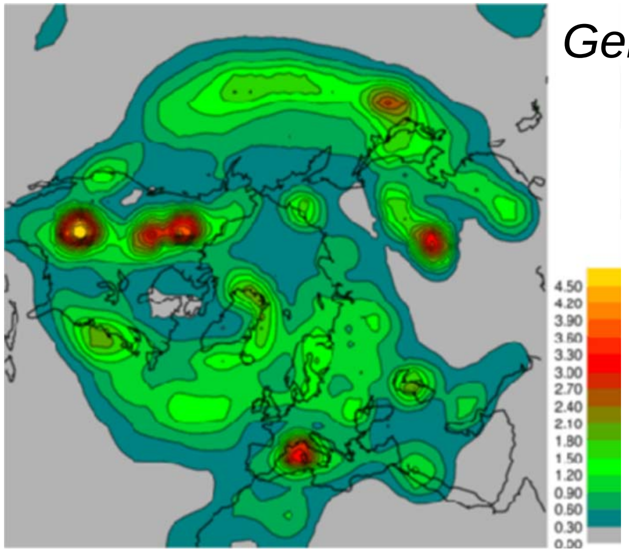


Applications of TRACK

- Climatological studies
  - Track density
  - Genesis
  - Lysis
- Compare re-analyses, differences in storm track
  - Spatial differences
  - Intensity differences
- Climate change studies
  - Differences in storm tracks with different warming scenarios



ERA15 DJF
Track Density



Genesis density

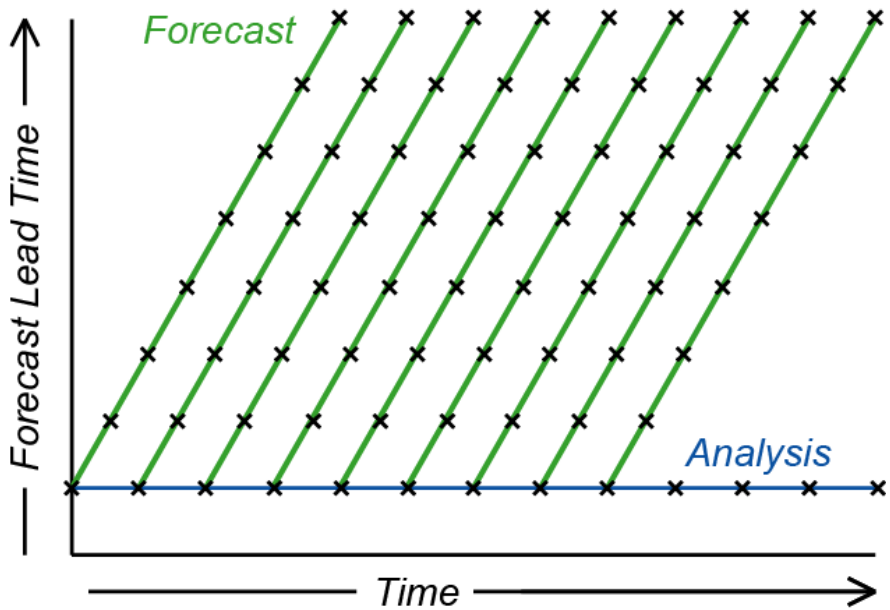
From Hoskins and Hodges (2002)

Forecast Verification

- Use TRACK as a tool for **forecast verification** and to explore the **predictability** of extratropical cyclones
- Forecast Skill often measured using RMS error of fields such as 500-hPa geopotential height
- Alternative Storm Tracking method:
  - Identify and track cyclones along the forecast trajectories
  - generate statistics to quantify how individual forecast storms diverge from analysed storms with forecast time
  - Provides detailed information about prediction of cyclones
  - Since storms fundamental to weather in midlatitudes, provides good measure of ability of NWP to predict weather

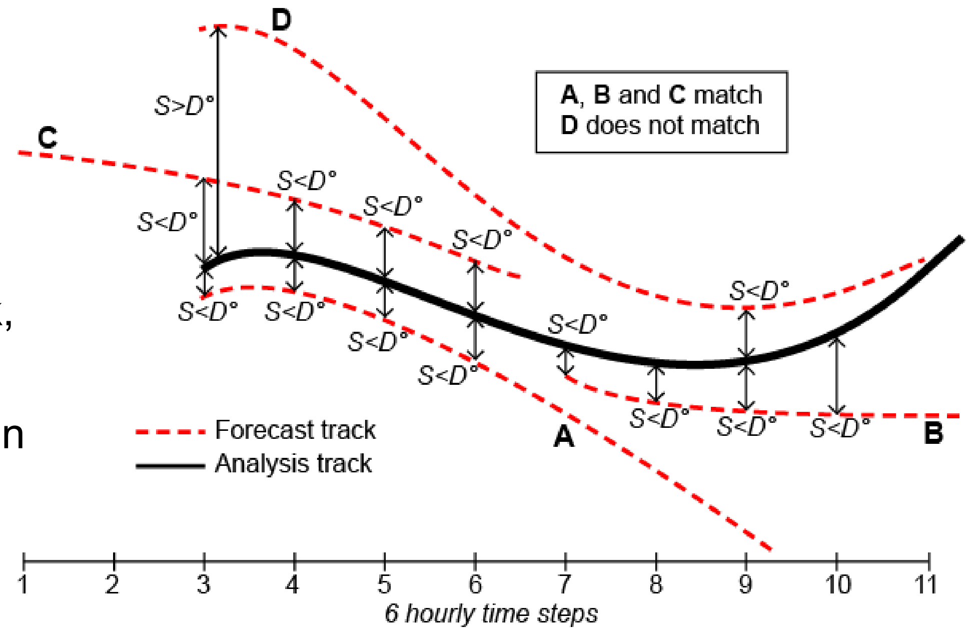
Storm Tracking Analysis Methodology

- Cyclones identified and tracked along forecast trajectories (green) using 850 hPa vorticity field
- Tracking also performed with corresponding analyses (blue)
- Forecast storm tracks validated against analysis storm tracks using a matching methodology
- Error statistics are generated for various properties of cyclones, e.g. position, intensity, propagation speed



Statistics: Matching Methodology

- A forecast track matches an analysis track if
  - *T*% of their points overlap in time (**temporal constraint**)
  - The first 4 points of the forecast track, which coincide with in time with the analysis track, must have a separation distance *S* of less than *D*° from the corresponding points in the analysis track (**spatial constraint**)



- 3 levels of matching:
  1. *T* = 60% and *D* = 2°
  2. ***T* = 60% and *D* = 4°**
  3. *T* = 30% and *D* = 4°
- Additional constraint – only those forecast tracks whose genesis occurs in the first 3 days of the forecast are considered

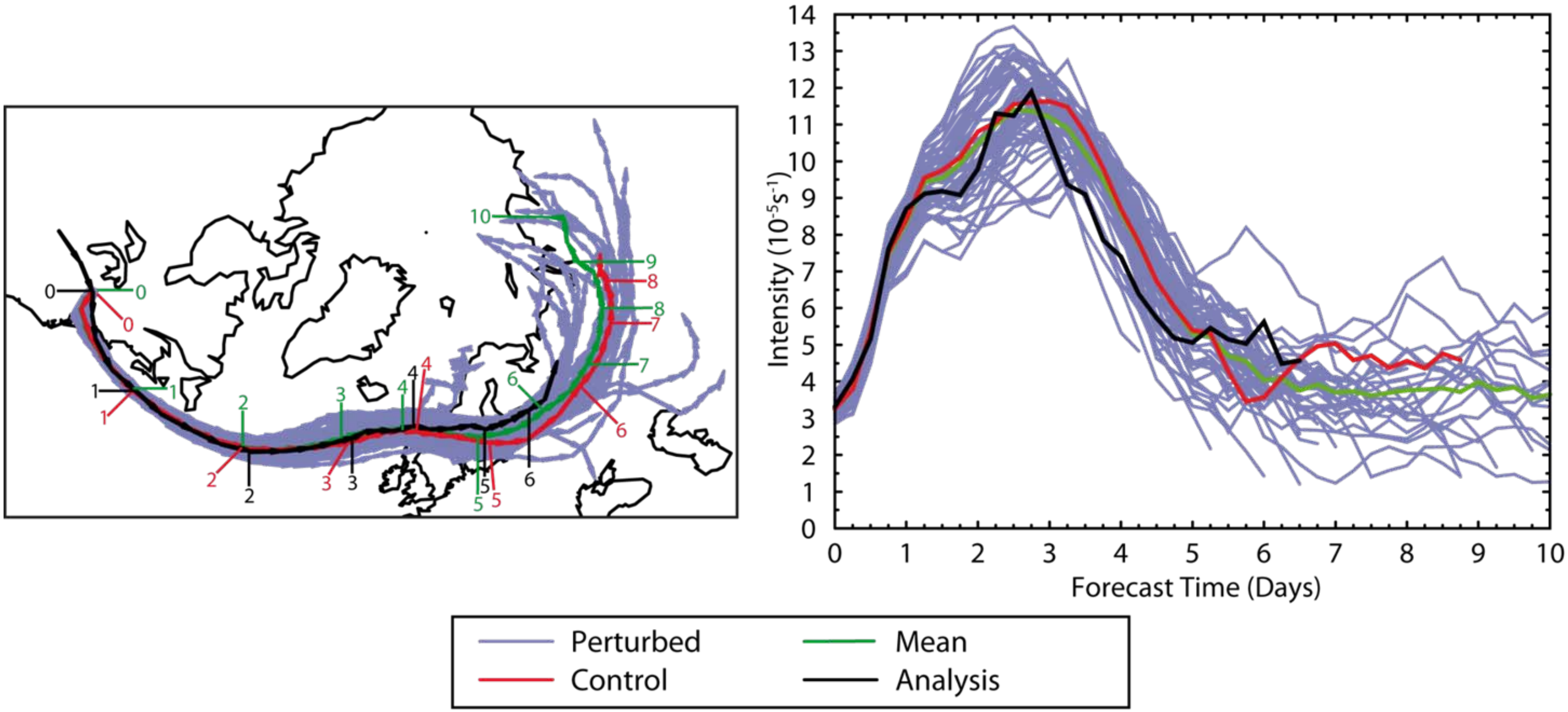
Ensemble Prediction

- Atmosphere chaotic: small errors in initial conditions grow rapidly during forecast
- Multiple forecasts are integrated from slightly different initial conditions
- Initial conditions obtained by applying perturbations to the analysis (truth)
- Control forecast started from unperturbed analysis, at same resolution as other ensemble members
- Sometimes perturbations also applied to forecast model
- Benefits of Ensemble Prediction:
  - Probabilistic forecast
  - Early warning of extreme events
  - Mean Forecast superior to control forecast

TIGGE Dataset

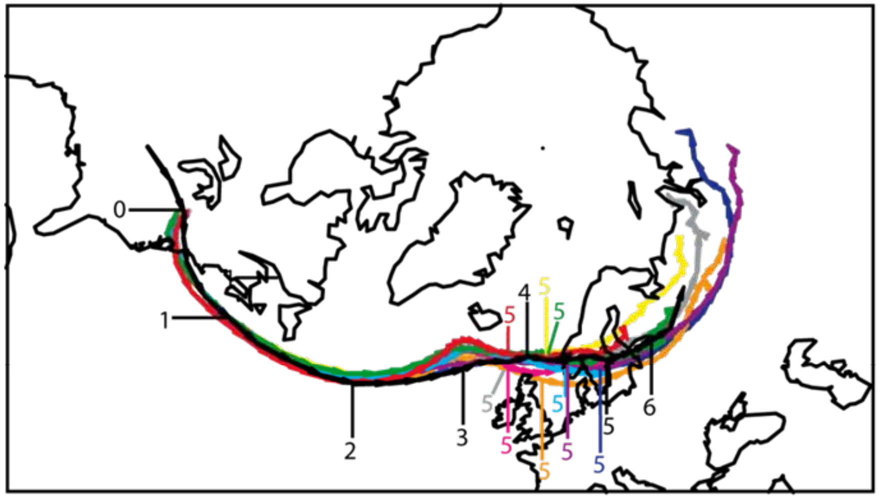
- THORPEX Interactive Grand Global Ensemble (TIGGE)
- Archive of EPS data from 10 different operational weather centres around the world
  – UKMO (UK), ECMWF (Europe), NCEP (USA), JMA (Japan), KMA (Korea), BoM (Australia), MF (France), CPTEC (Brazil), CMC (Canada), CMA (China)
- Each EPS different
  – Different perturbation methods, models, no. of members, model perturbations, resolution, data assimilation
- Analyse the prediction of storms by different EPS
- Data period: 1 Feb 2008 – 31 Jul 2008
- Tracking performed along each ensemble member and control forecast of each EPS
- Verify against ECMWF analyses

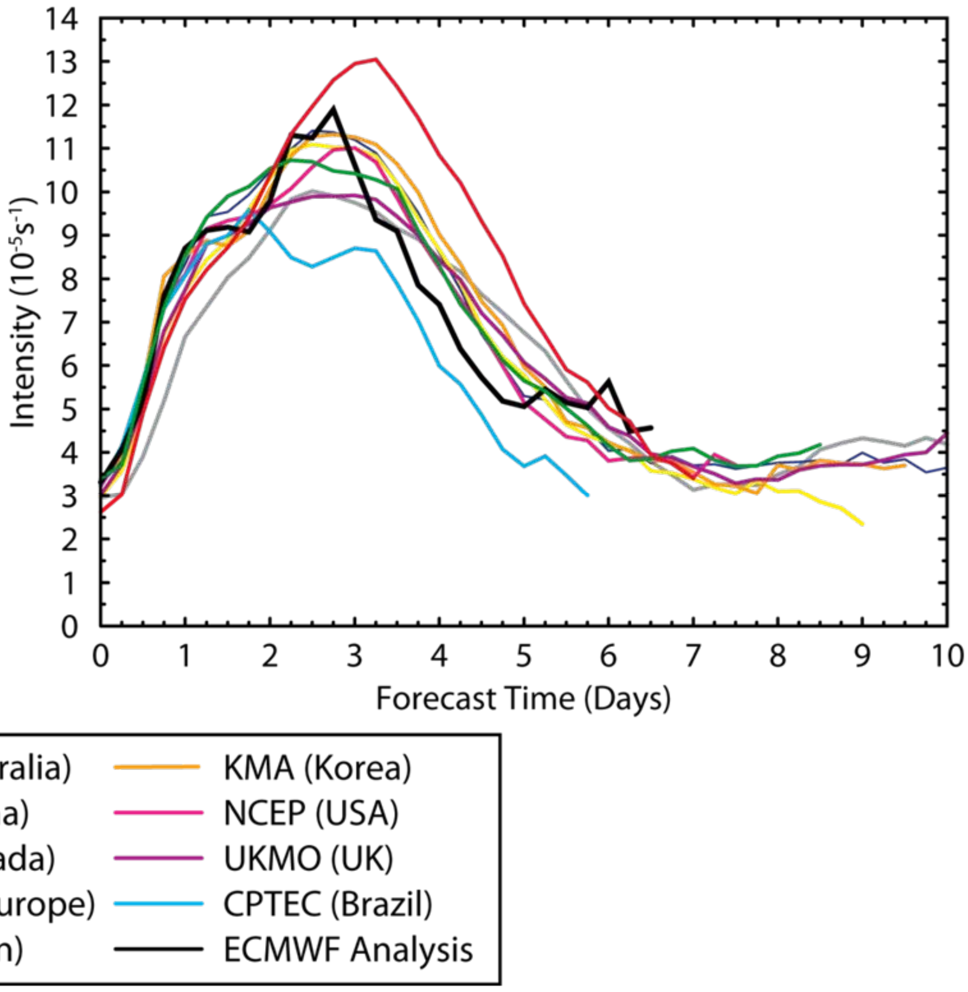
ECMWF Example Storm



Forecast started 1200 UTC 4 Feb 2008

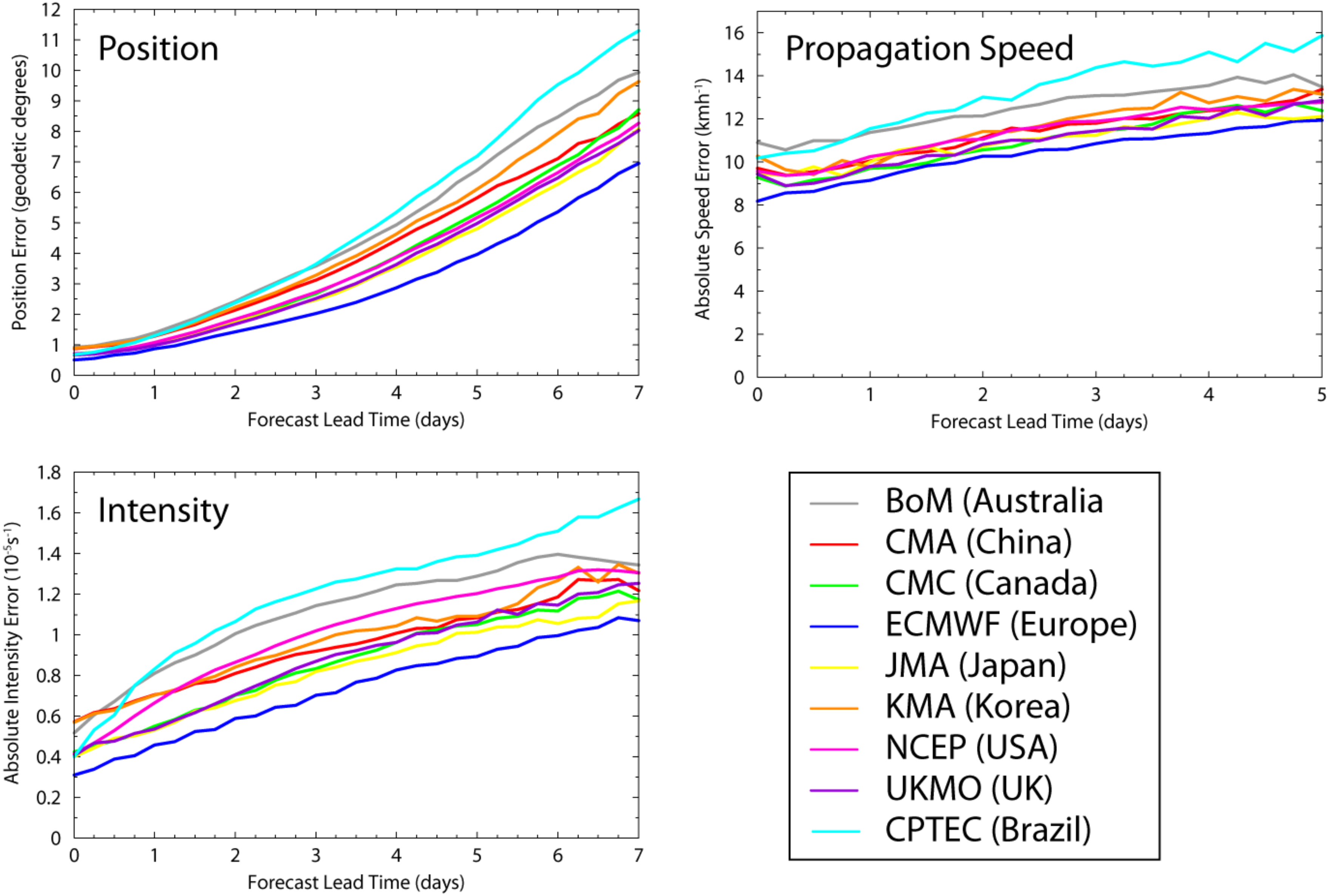
TIGGE: Ensemble Mean



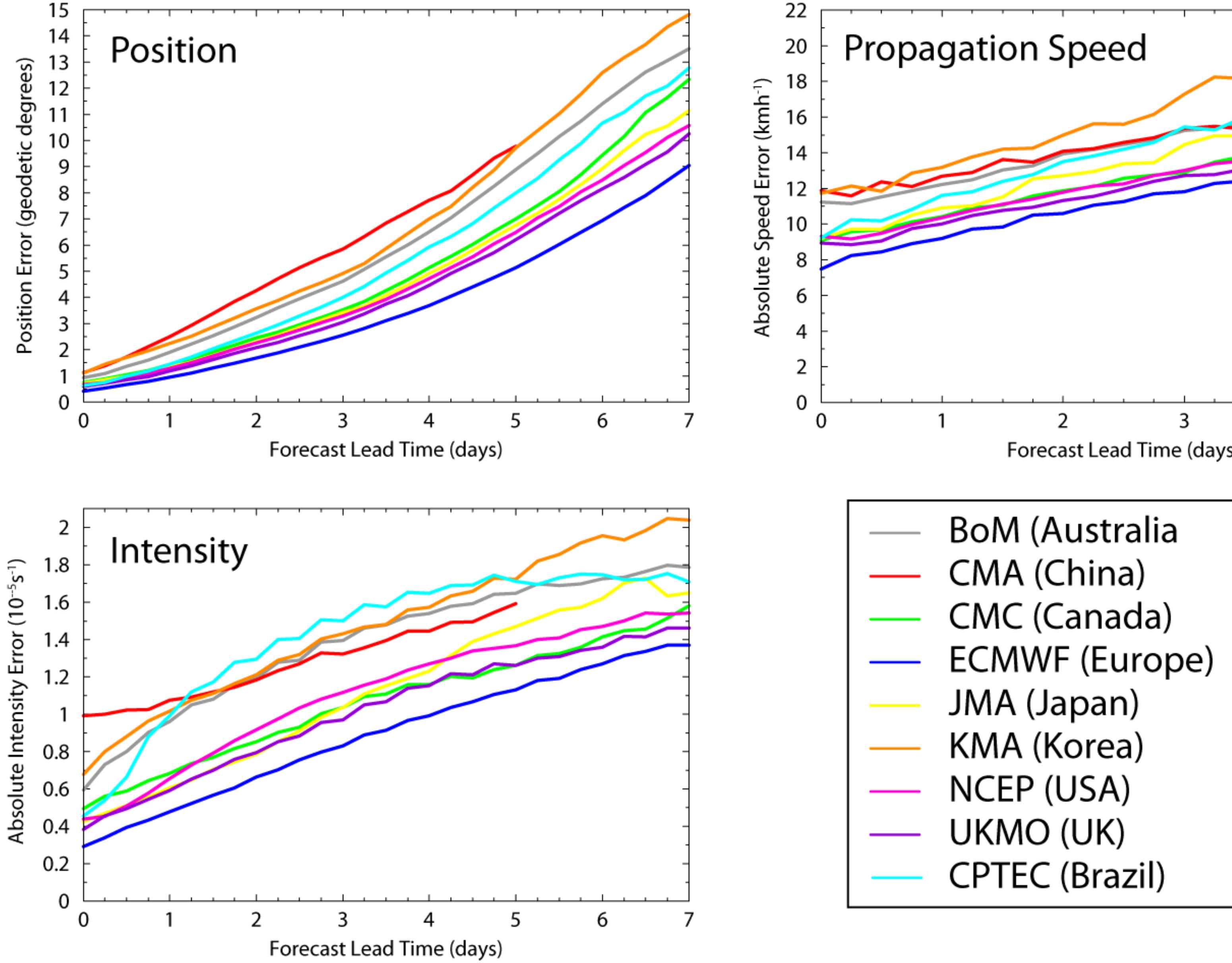


Forecast started 1200 UTC 4 Feb 2008

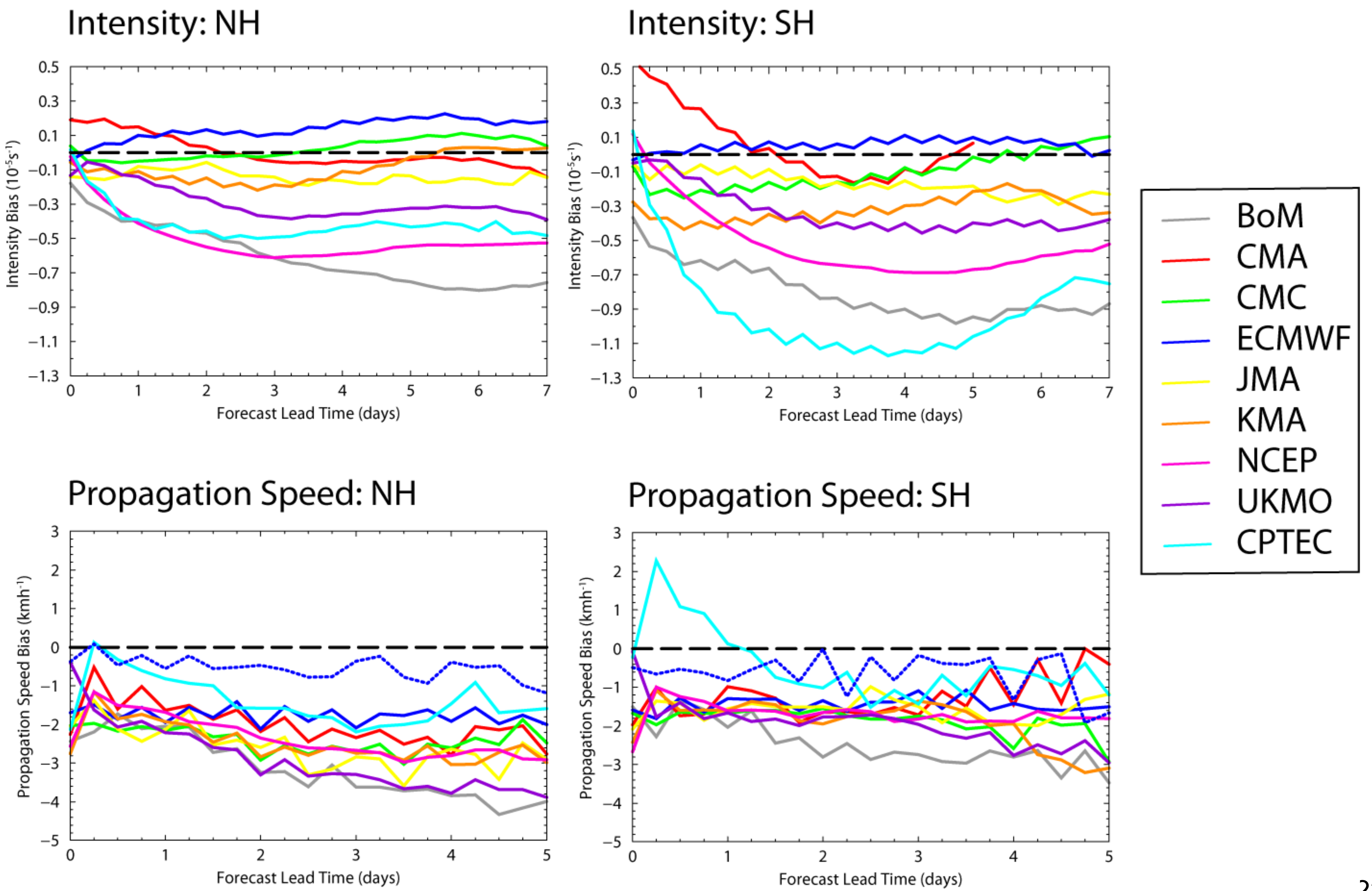
Ensemble Mean Error (northern hemisphere)



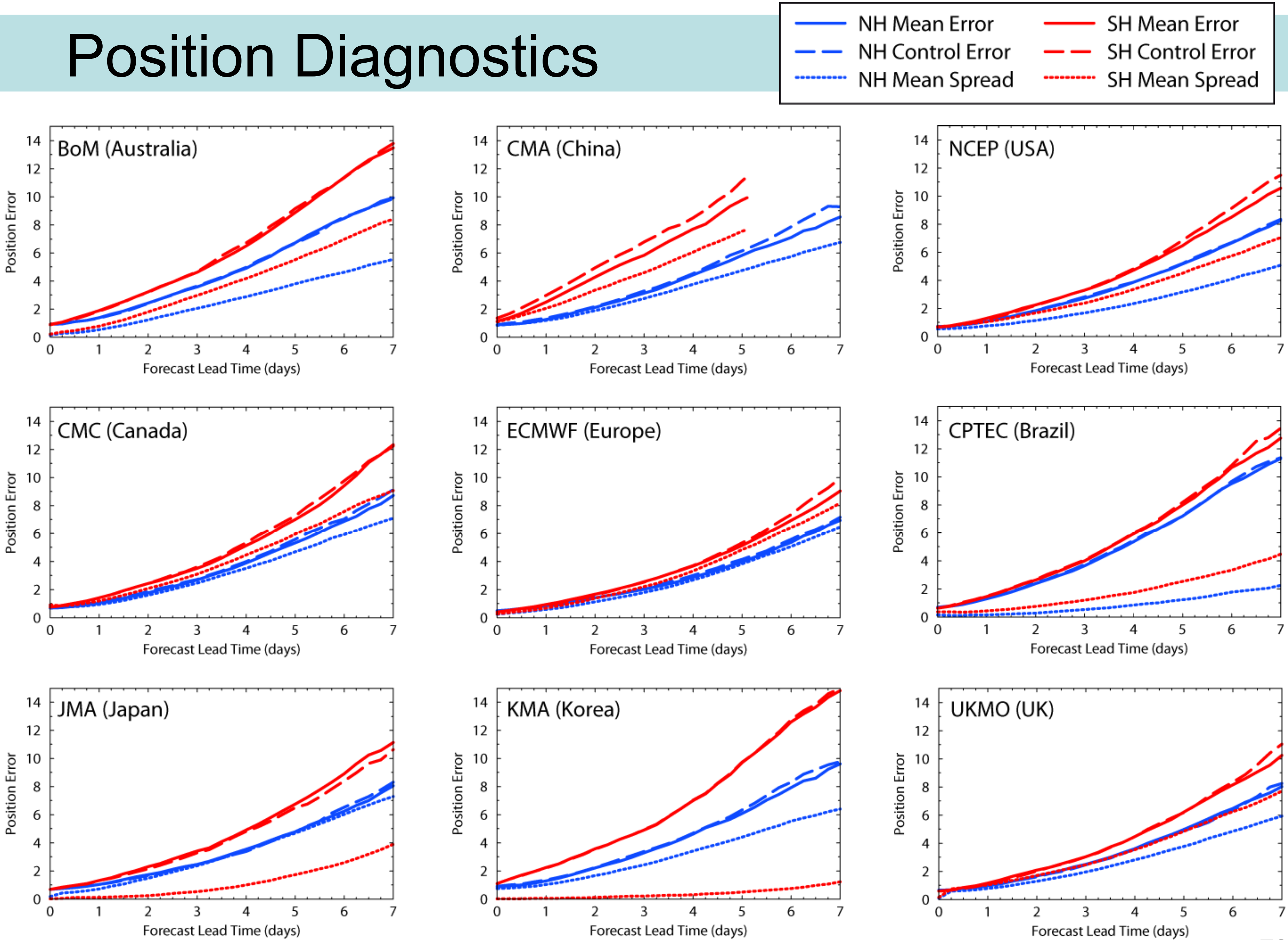
Ensemble Mean Error (southern hemisphere)



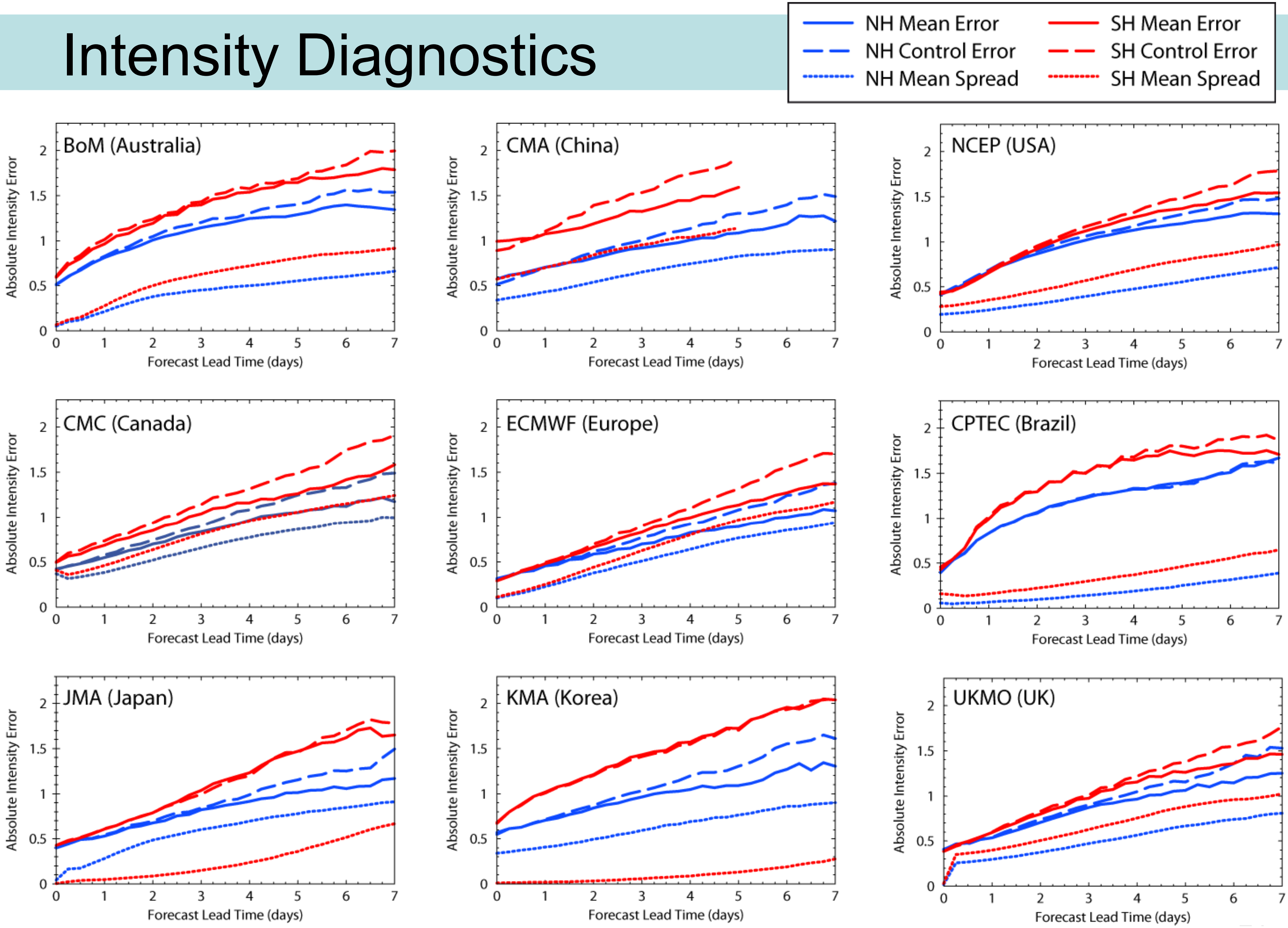
Intensity and Propagation Speed Bias



Position Diagnostics



Intensity Diagnostics



Summary: TIGGE Results

- Large differences between different EPS in skill of predicting storms
- ECMWF has highest skill for ensemble mean and control
- Ensemble mean provides little advantage over control for position, but does for intensity
- ECMWF and JMA have excellent spread-skill relationship for position
- EPS are much more underdispersive for intensity and speed
- Storms propagate too slowly in all models
- UKMO, NCEP, BoM and CPTEC underpredict storm intensity, other EPS have smaller bias
- CMA large errors in SH

Regional Differences in ECMWF EPS

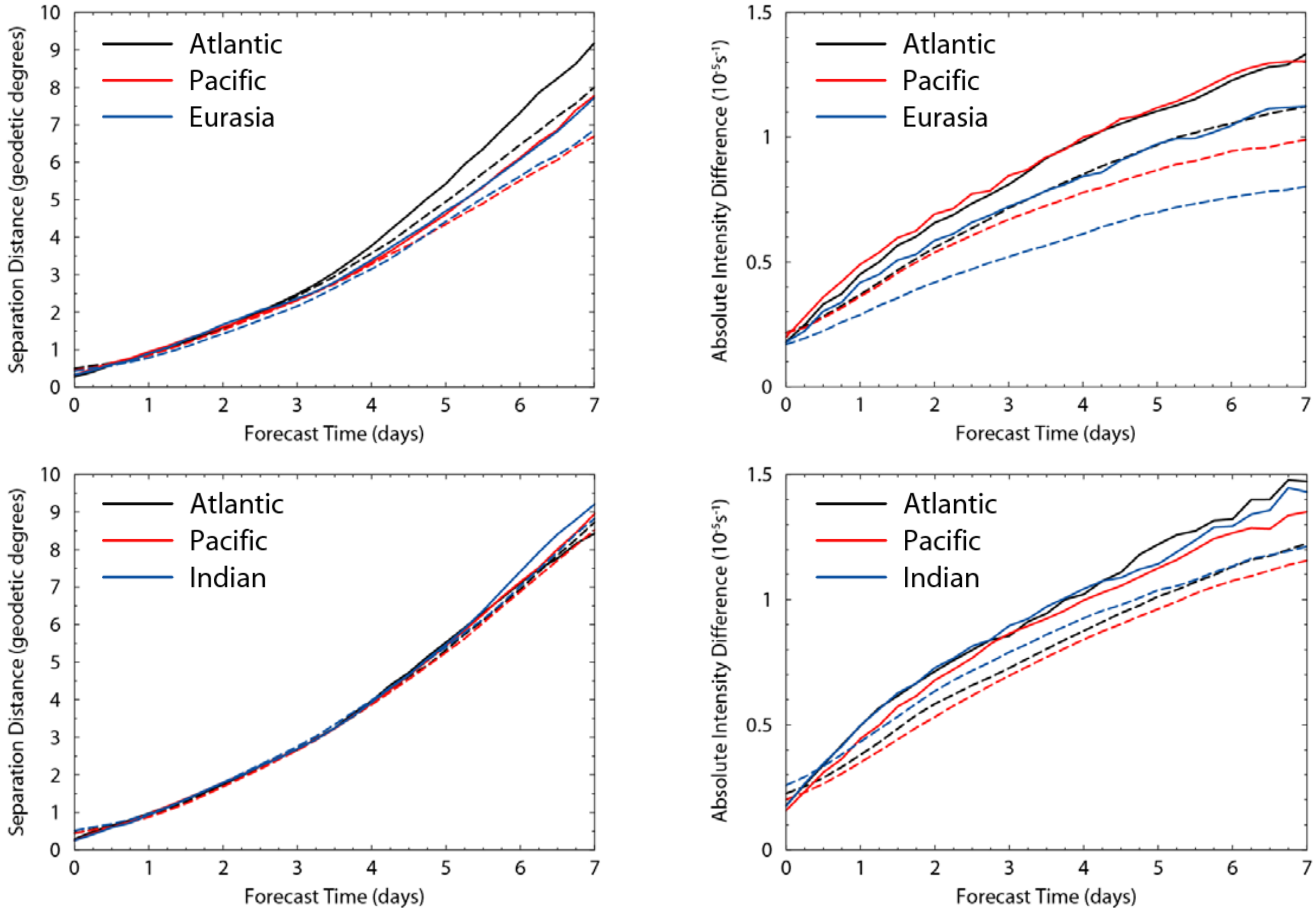
- **1 year of data: 6th Jan 2005 – 5th Jan 2006**
- **Larger data sample allowed storm-track analysis to be broken down into smaller regions**
- **Northern Hemisphere (Above 20N):**
  - Atlantic = (280º,0º)
  - Pacific = (120º,240º)
  - Eurasia = (0º,120º)
  - North America = (240º,280º)
- **Southern Hemisphere (Below 20S):**
  - Atlantic = (300º,0 º)
  - Pacific = (150º,290º)
  - Indian = (20º, 120º)

Ensemble Skill and Spread

Position Error | *Intensity Error*

Northern Hemisphere

Southern Hemisphere



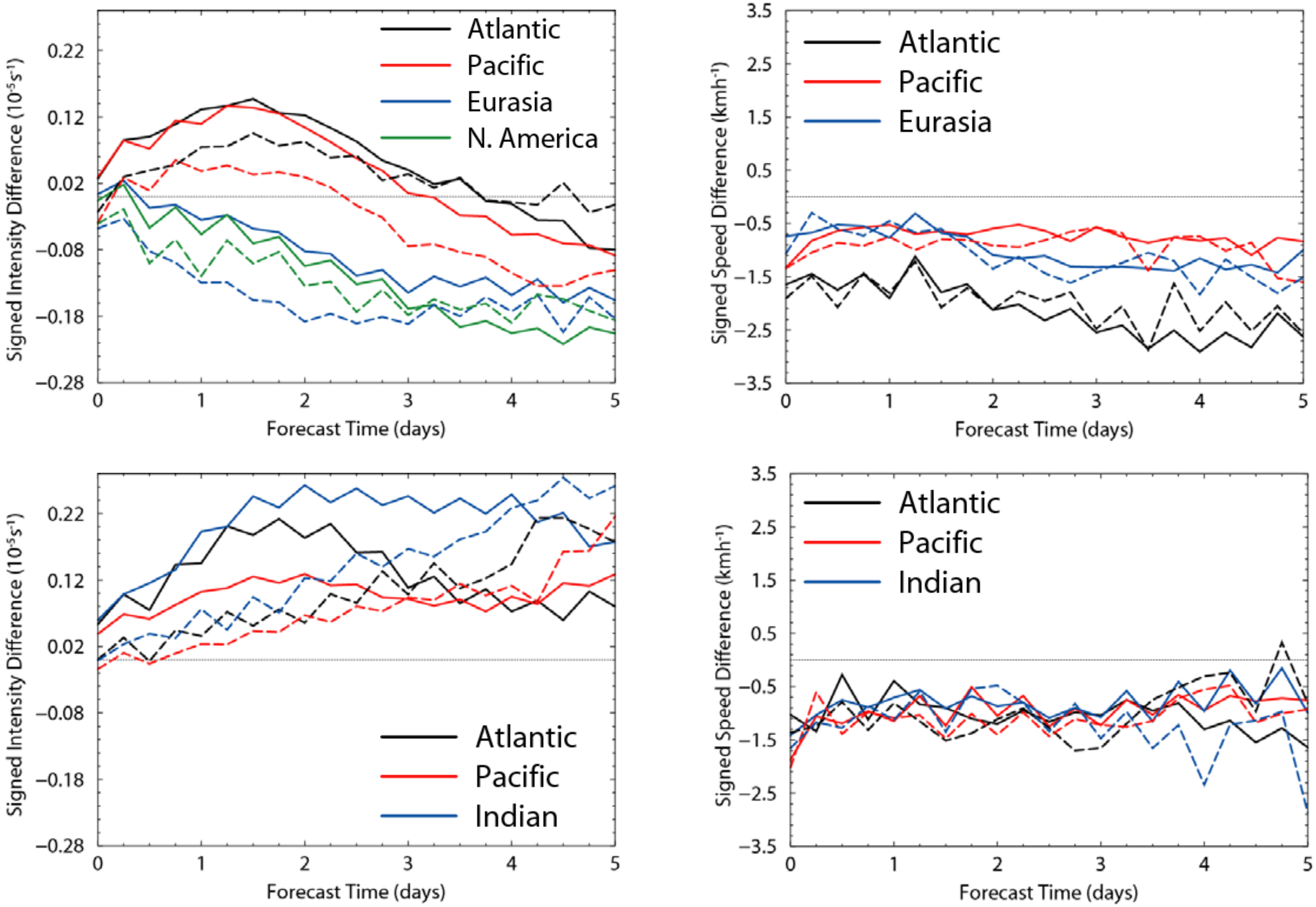
Solid = ensemble mean error, Dashed = ensemble spread

Intensity and Propagation Speed Bias

Intensity Bias | *Speed Bias*

Northern Hemisphere

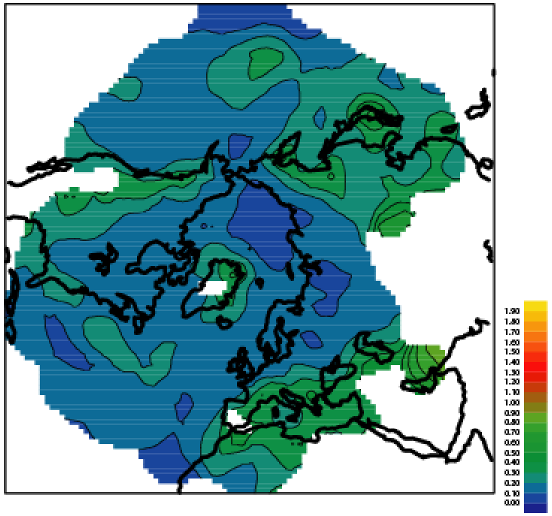
Southern Hemisphere



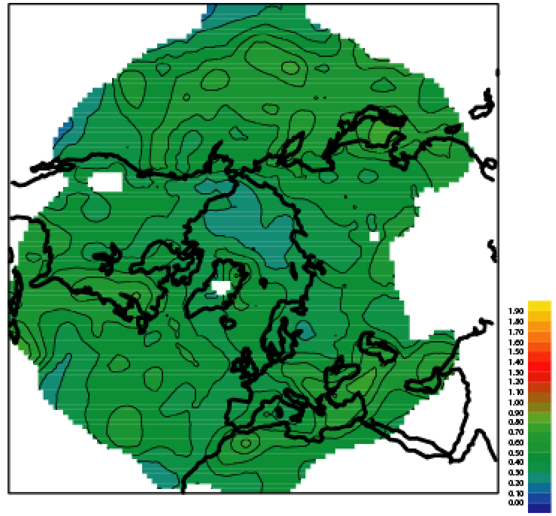
Solid = perturbed members, Dashed = control

NH Mean Intensity Error

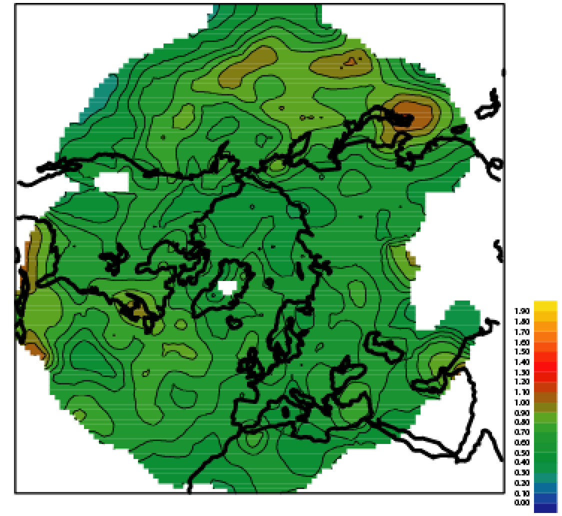
REMOVE TROPICAL CYCLONES



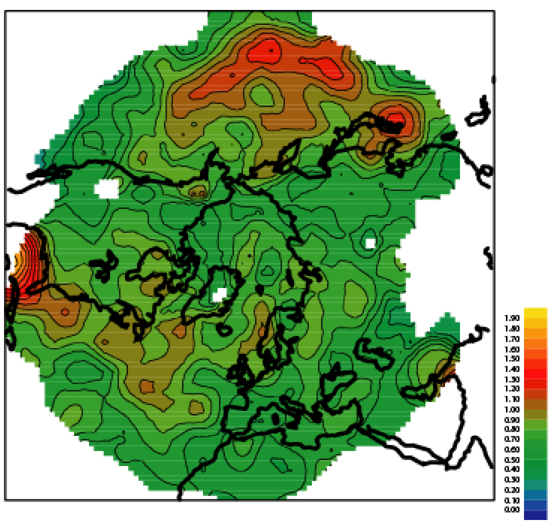
Day 0



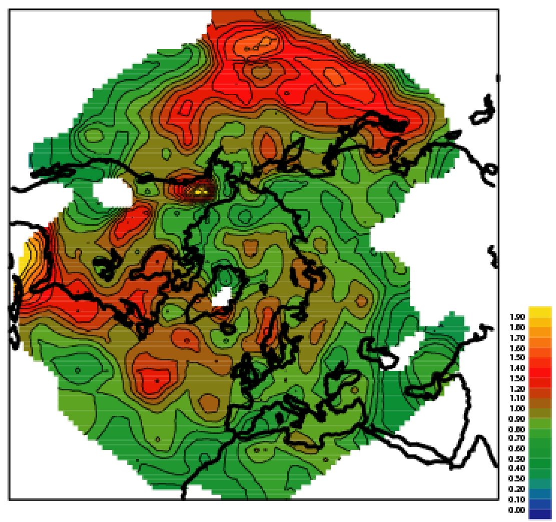
Day 1



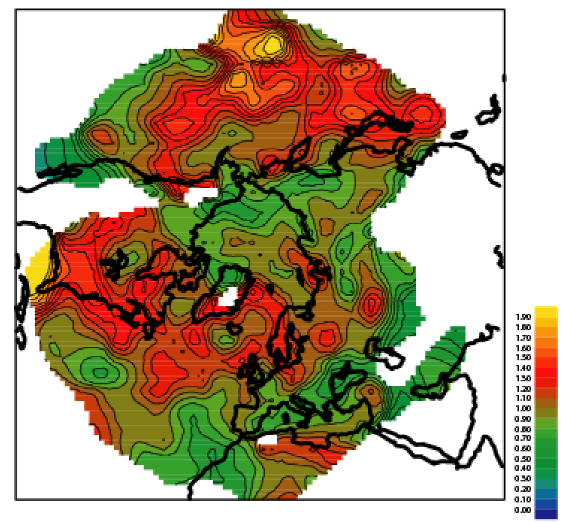
Day 2



Day 3

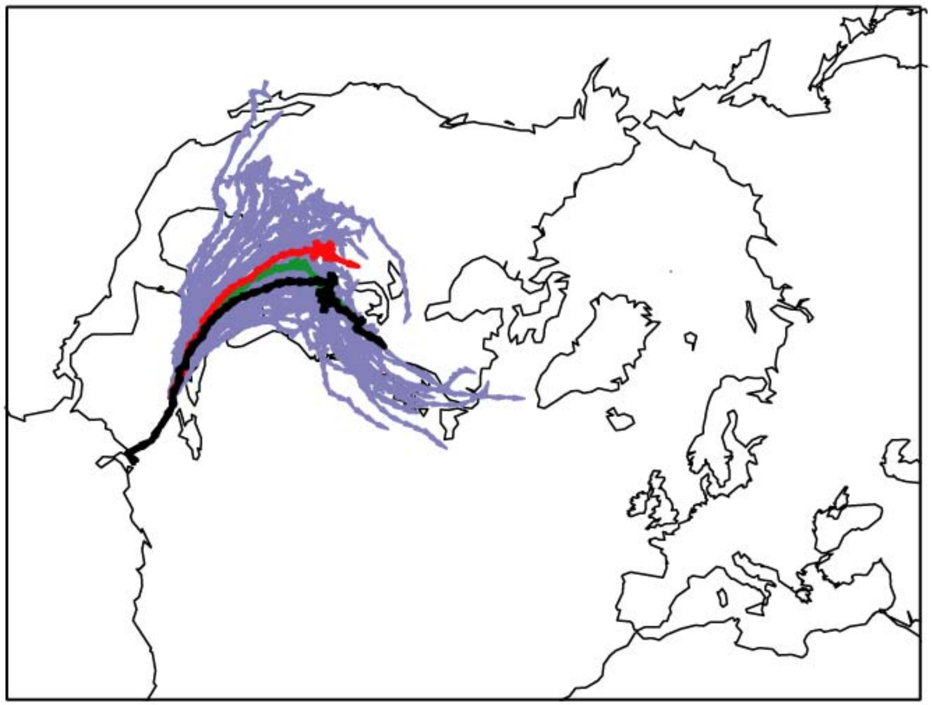


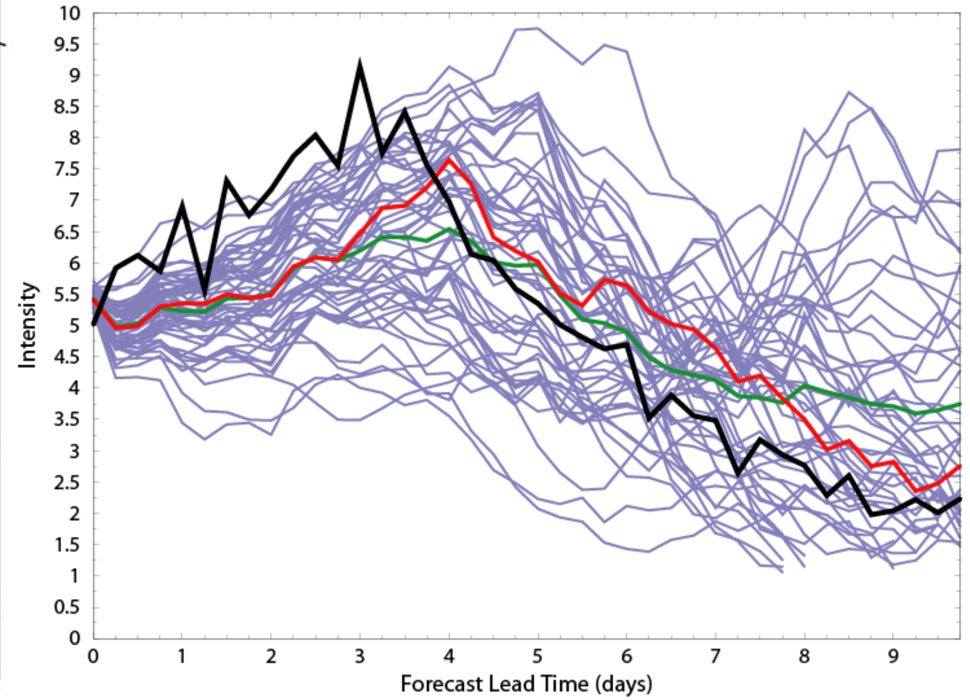
Day 4



Day 5

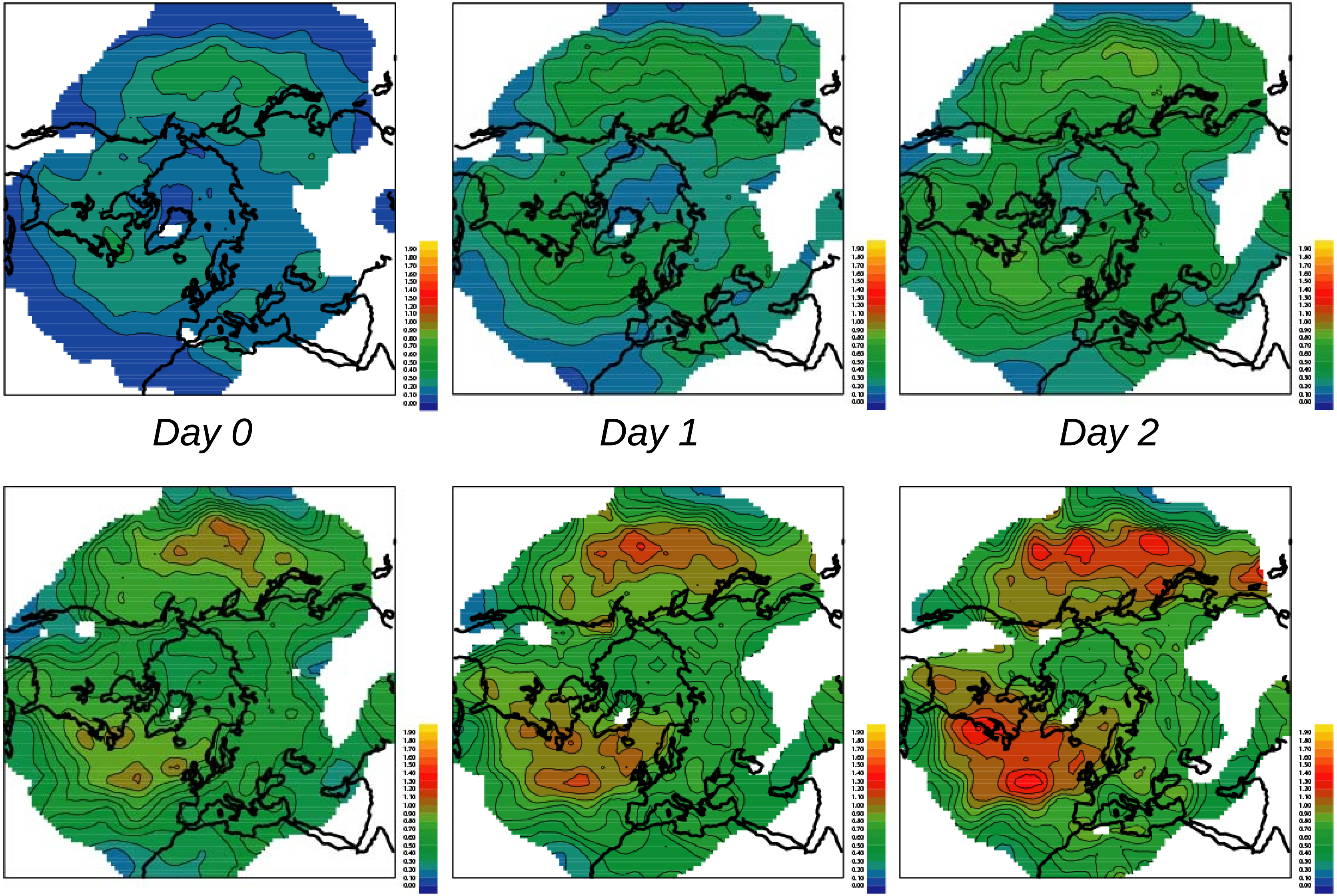
Storm Example (July 2005)





Black = truth, Red = control, Blue = ensemble members, Green = mean

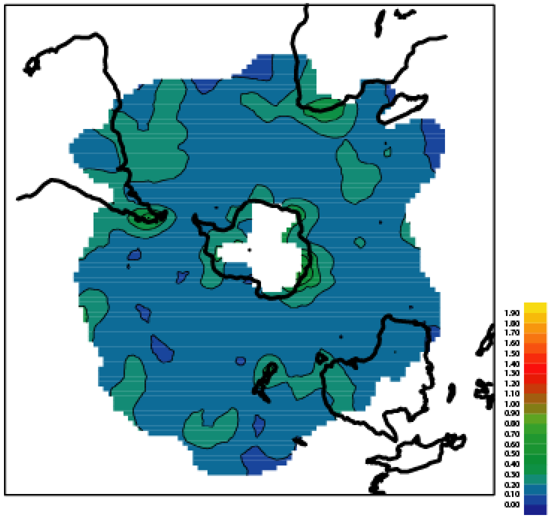
NH Intensity Spread



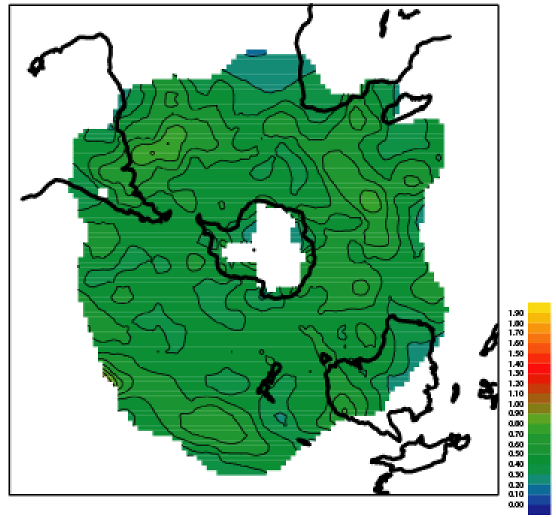
Day 0 | Day 1 | Day 2

Day 3 | Day 4 | Day 5

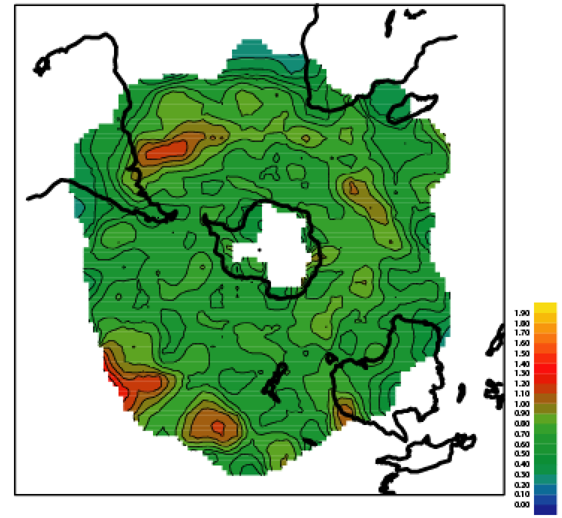
SH Mean Intensity Error



Day 0



Day 1



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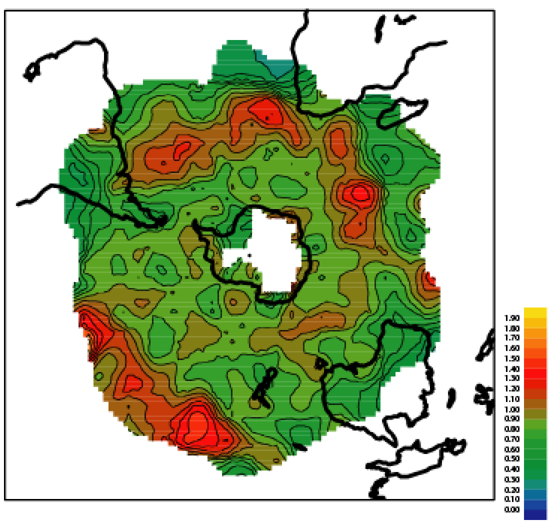
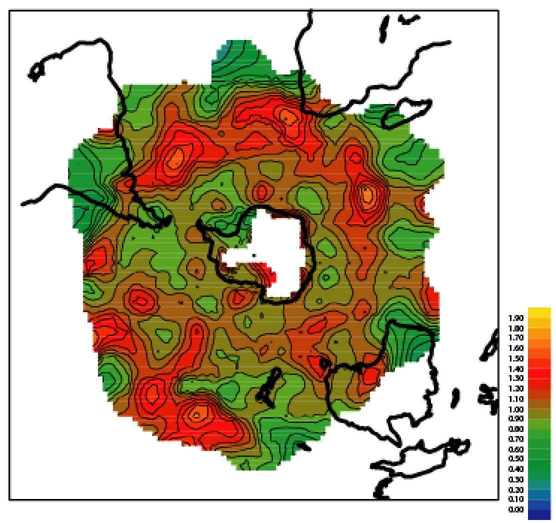
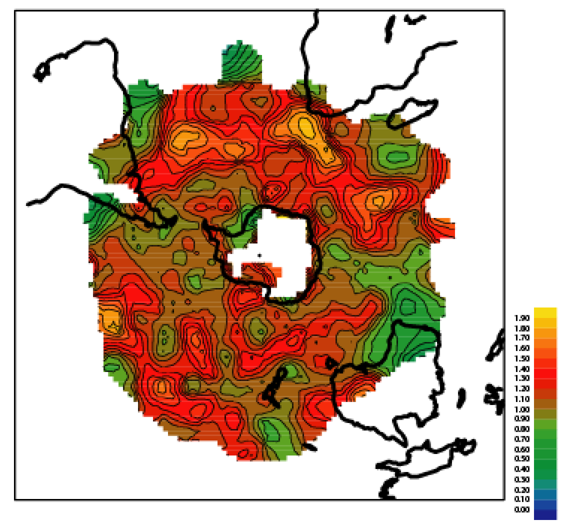


Day 3

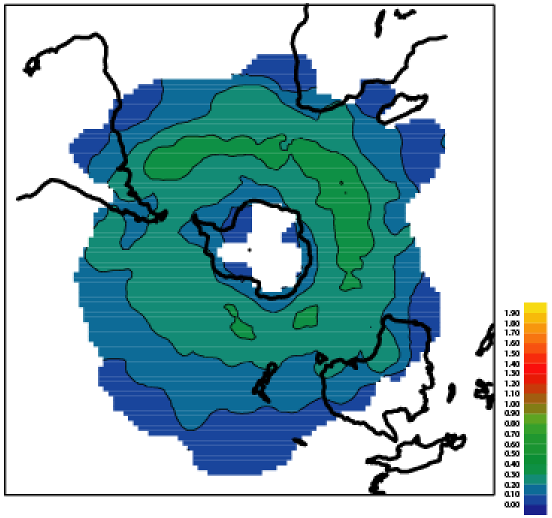


Day 4

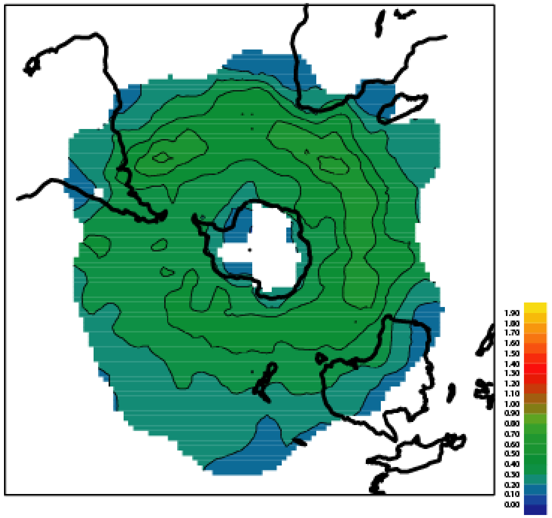


Day 5

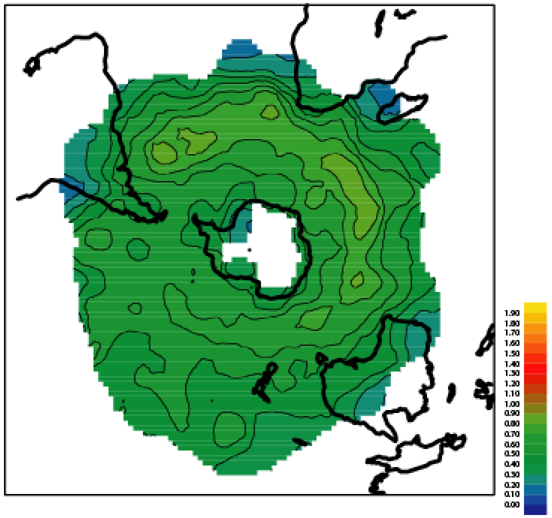
SH Intensity Spread



Day 0



Day 1



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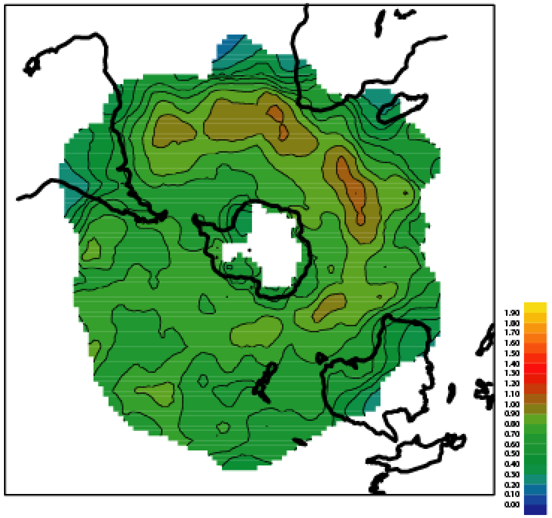

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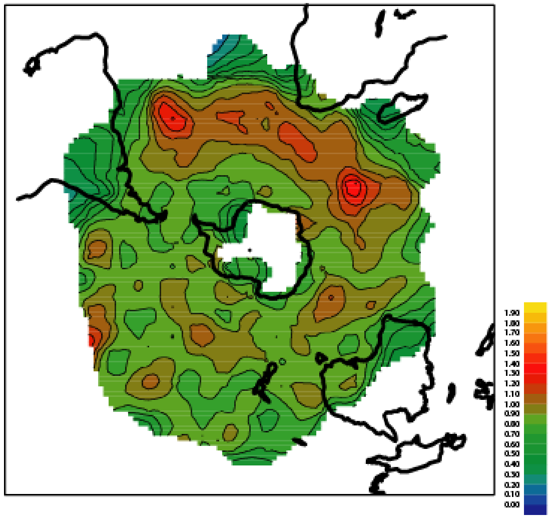
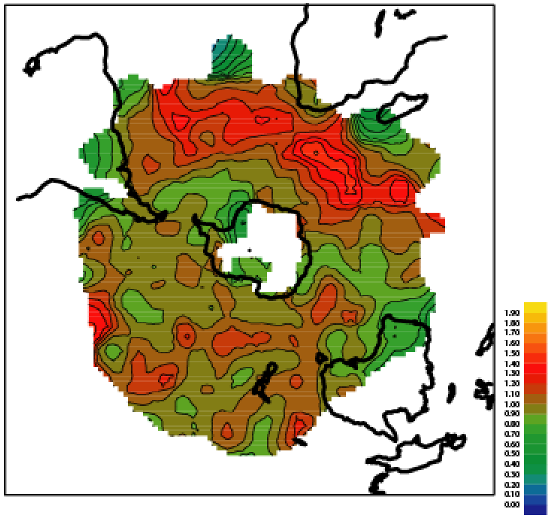


Day 4



Day 5

Summary: Regional Results (ECMWF EPS)

- Error in position is larger over the Atlantic in NH, larger in SH but comparable between regions
- Error in intensity is larger over the ocean than over land
- Spread in position is slightly less than mean error from day 3 for all regions in NH, but comparable in SH
- Spread in intensity is less than mean error for all regions, larger difference for NH Pacific and Eurasia
- In general storms are overpredicted over the ocean and underpredicted over the land
- Forecast storms move too slowly; larger bias over the Atlantic in the NH

What Next?

- New project working with company BMT ARGOSS (http://www.argoss.nl/)
- Develop forecast tools providing storm prediction/ uncertainty information from NCEP EPS for decision making at sea

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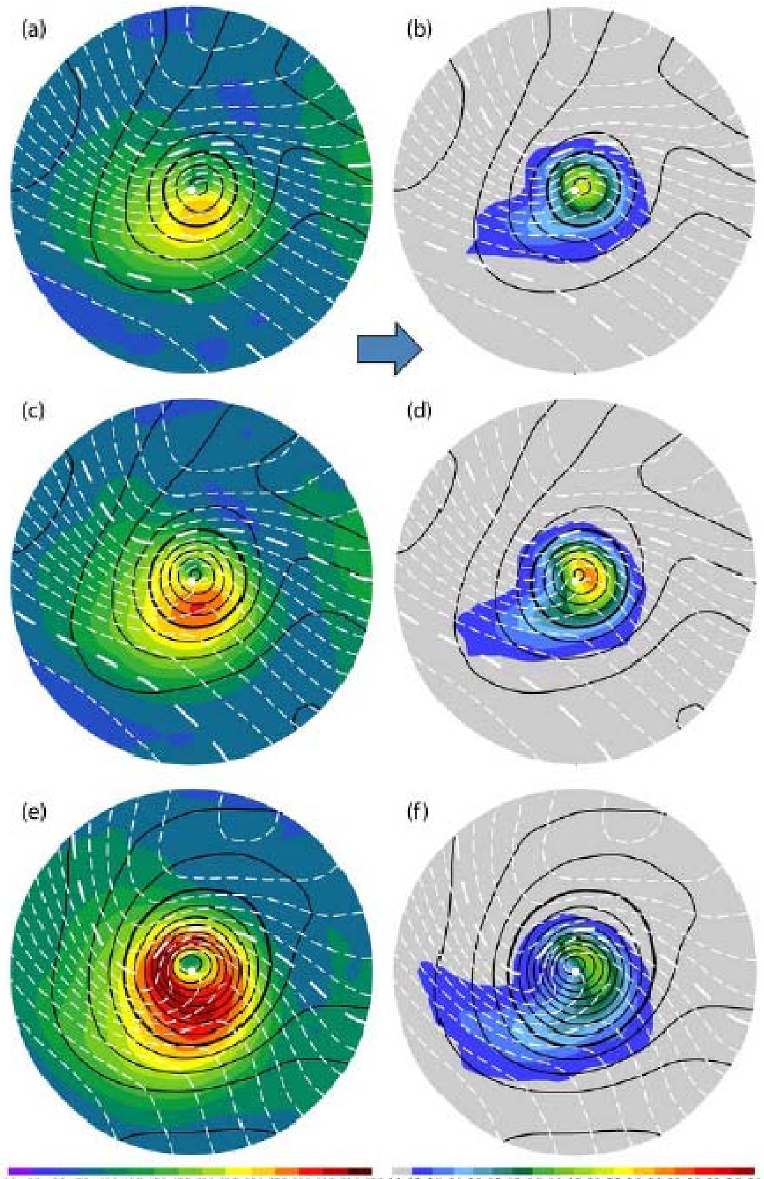
- Explore the causes of error in storm prediction/ predictability
- Storm composites, vertical structure, tilts, lifecycles – further understanding of errors in relation to storm dynamics
- Forecast experiments to access impacts of resolution, perturbation methods, no. of ensemble members etc.

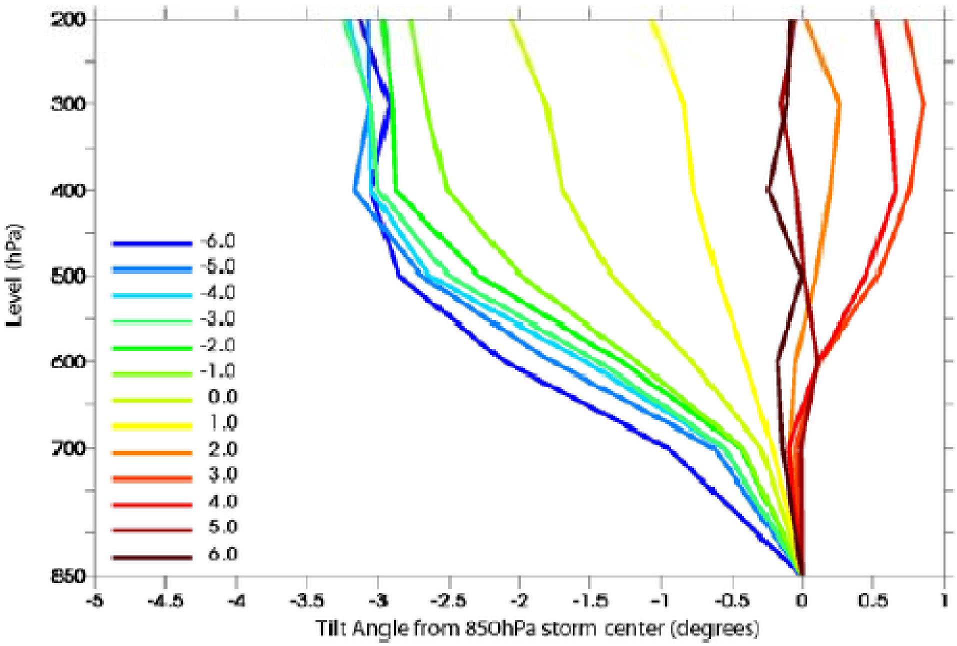
ERA40 Storm Composites



- 100 most intense storms in T42 ξ_{850} at different stages of lifecycle
- NH, DJF
- Top = max growth rate
- Middle = max precipitation
- Bottom = max T42 ξ_{850}

- Left = mean wind speed (colour, m/s)
- Right = mean precipitation (colour, mm/h)
- Black contours = mean MSLP (hPa)
- White dashed contours = temperature between 850 and 500 hPa

ERA40 Storm Vertical Tilt Life Cycle Composites



- Vertical tilt of 100 most intense storms at different stages of lifecycle
- Time steps 6hr apart
- Time step 0 = maximum T42 ξ_{850} intensity
- Tilts are angle from 850-hPa centre

- Interesting to look at structure and tilt of cyclones predicted by different EPS
- Different perturbation methods and cyclone structure
- Overprediction and underprediction, differences in structure…

Final Remarks

- Storm tracking methodology provides detailed information about prediction of cyclones by NWP
- Alternative method of forecast verification
  - **Advantage:** provides detailed information about prediction of storms – good measure of how the weather is predicted
  - **Disadvantage:** Time consuming, requires large amounts of data
- Useful to both forecasters/users and model developers

email: lsrf@mail.nerc-essc.ac.uk homepage: www.nerc-essc.ac.uk/~lsrf